The mechanical properties of six finger trap suture techniques

Digital Object Identifier (DOI):
10.1111/vsu.12656

Published In:
Veterinary Surgery

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Naomi F Earley[1], BVSc, Lee Meakin[2], MA VetMB, MRes, PhD, Kevin J Parsons[2], BVSc, PhD, Cert SAS, Diplomate ECVS, John Tarlton[2], BSc, PhD, Jon L Hall[1], MA VetMB, Cert SAS, Diplomate ECVS

[1] Queens Veterinary School Hospital, University of Cambridge, Cambridge, UK

[2] School of Veterinary Sciences, University of Bristol, Bristol, UK

There was no funding or grant received for this study.

Abstract was presented at the AVSTS spring meeting, Birmingham, UK, April 2015.

Corresponding author:

Miss Naomi F Earley

23 Lambourne Road, Hardwick, Cambridge, CB23 7XB, UK

naomiearley@hotmail.com

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Abstract

Objective:

To identify the most commonly tied finger trap sutures (FTS), determine whether these patterns behave differently using mechanical testing, and ascertain which were most secure. Secondarily, to establish whether the number of repeats performed affected the FTS behavior.

Study Design:

Questionnaire and experimental study.

Methods:

Six commonly used FTS methods (A-F) were identified from literature review and questionnaire. Mechanical testing of patterns using 3 metric nylon suture and 18 French polyurethane esophagostomy tubing was performed. The effect of altering the number of repeats (2, 4 and 8 repeats) along the tube was investigated using 2 patterns (B and D). Samples were loaded to failure under continuous distraction. Displacement and force data were measured and failure mode was video recorded.

Results:

Patterns E and F were susceptible to slipping ($p<0.001$). Patterns A and D were stiffer than pattern E, and patterns A-D were stiffer than pattern F ($p=0.012$). Patterns A and B had less extension than pattern E and F, and patterns A-D had less extension than pattern F ($p=0.002$). 87.5% of FTS failed by breaking at the first suture knot. The number of repeats had no effect on FTS performance.

Conclusions:

The mechanical behavior of suture-tube constructs and failure mode is affected by the FTS pattern. Patterns E and F are not advocated due to suture slippage. The number of repeats may not affect the FTS performance. Overall, patterns B, C and D performed the best using this methodology. Further study using different tube and suture constructs is warranted.

Introduction

Finger trap sutures (FTS) are constructs that are commonly used to secure temporary tubes and catheters to the skin and prevent dislodgement. [1] They are designed to tighten as tension is applied, ideally providing security without constricting the tube lumen. [2] The FTS has also been referred to as the Chinese FTS, [1, 2, 3, 4, 5, 6] Roman sandal suture [7, 8, 9] or Roman garter suture. [10] Alternative methods to secure tubes such as adhesive tape and circumferential sutures are less effective. [1]

Multiple different techniques for tying FTS have been reported [1, 2, 4, 6, 7] but these descriptions have been unclear and it is is not known which is the most effective technique. It is self evident that secure tube placement is fundamentally important. Complications resulting from failure of tube fastening include premature displacement, tube kinking, obstruction and tube migration. [2, 8, 11, 12, 13, 14] Gastrostomy, enterostomy or thoracostomy tube disruption can result in peritonitis [12] or pneumothorax respectively. [13] One study reported thoracostomy tube complications in 22% of cases, including a dog with fatal pneumothorax. [13] Replacing dislodged catheters and tubes increases patient morbidity, treatment cost, is time consuming [1] and often requires a general anaesthetic. [14]

FTS have been compared with other suture types, for example Song et al. [2] compared the failure mode of the Chinese FTS and 4 simple interrupted friction sutures. The FTS was quicker to place and had a longer mean displacement to failure compared to the friction suture when undergoing axial loading. [2] Ricker et al. [15] reported no significant difference between 3 patterns of FTS, using 2 different types of catheter material and 2 different suture materials. [15] The study suggested that the surface characteristics of a tube alters the coefficient of friction between tube and suture, and the ability of the arms of the FTS to slide over each other at suture intersections affected the ability of the suture to grip the tube. However, there were no clear reasons to select the FTS patterns investigated and multiple variables were altered making it challenging to draw firm conclusions. Finally the materials used in the study were not materials commonly used in current clinical practice (e.g. braided nylon and narrow 5 French diameter tubing).

The aims of this study were to determine which patterns are most frequently tied by surgeons using a questionnaire, and then to determine whether a particular pattern outperformed the others using distraction to failure mechanical testing to mimic the tube being accidentally pulled or intentionally disrupted by the patient. We wished to design a study comparing relevant materials commonly used in veterinary patients for the most frequent indications to secure a tube. We hypothesised that some FTS patterns would perform better than others (e.g. resist greater loads and resist slipping) and aimed to publish clear guidelines for tying the best performing patterns.

Materials and methods

A questionnaire was circulated by the Association of Veterinary Soft Tissue Surgeons and the Veterinary Society of Surgical Oncology to member veterinary surgeons, including ECVS and ACVS diploma holders, asking them to describe their preferred method, uses of, and complications they have experienced with FTS (Appendix 1). The term 'square knot' was defined as a single throw, followed by a second throw in the opposite direction. [4] A 'surgeons' throw' was defined as a double throw. The term 'surgeons' knot' was defined as a double throw (or surgeons' throw), followed by a single throw in the opposite direction. [4]

Part 1: Comparison of suture patterns

The 6 most common FTS patterns were identified by literature review (Patterns A [1], D [2] and E [6]) and questionnaire (Patterns B, C and F) (Appendix 2). Twelve sutures were tied for each of the 6 patterns using 3 metric nylon suture (Ethilon™; Ethicon, Johnson & Johnson Medical Limited, Wokingham, UK). All sutures were tied using a two-handed technique by the same investigator (KP). A suture loop was created around a 5mm diameter steel cylinder (representing the skin attachment of the FTS) and a square knot created leaving suture ends of equal length. The suture ends were then tied around a 20cm length, 18 French diameter dedicated esophagostomy polyurethane tubing (Esophagostomy tube E1380, MILA International, Inc., Erlanger, Kentucky). Each throw or knot was tightened to slightly indent the tube but not occlude the lumen. For all suture patterns, there were a total of 6 repeats (number of throws or knots along the top surface of the tube).

Part 2: Comparison of number of repeats

Testing of patterns B and D using 2, 4 and 8 repeats was also performed (n=8 for 2, 4 and 8 repeats for each pattern; total = 48 constructs).

Samples were held between 2 mounted grips in a materials testing machine (Instron 3367; Instron, High Wycombe, UK). A 6cm section of the tubing was fixed in the clamp at the top of the machine and the suture loop beginning the FTS was secured to a grip at the bottom of the machine. A ruler was positioned adjacent to the suture construct. The distance between the 2 grips was adjusted to hold the suture construct taut with minimal force (Fig 1). The samples were loaded to failure through axial loading, with a continuous distraction force at a rate of 6mm/min. Experiments were video recorded for analysis. Displacement and force data was measured using computer and data acquisition software (Bluehill 3; Instron, High Wycombe, UK). Variables recorded were maximum load to failure (N), energy at failure (J) and extension at maximum load (mm). Suture slippage of the first knot of the FTS and failure mode was measured by analyzing the video recordings. Load extension graphs were plotted and stiffness was calculated using the gradient of the linear aspect of the graphs. Failure mode was recorded as suture slippage if the suture slid over the tube more than 40mm. The location of suture breakage was recorded.

Statistical analysis

Data was recorded as mean ± the standard error of the mean. Statistical analysis was performed using SPSS for Windows (version 21; IBM SPSS Statistics, Chicago). A one-way ANOVA was used to compare values of load at failure, energy at failure and extension at maximum load between the six methods with post-hoc least significance difference (LSD) analysis performed where $p<0.05$. A two-way repeated measures ANOVA was used for part 2 (comparison of the number of repeats).

Results

Twenty-seven questionnaires were returned. The most common uses of FTS described were to secure feeding tubes (n=25), chest drains (n=22), abdominal drains (n=21) and wound drains (n=9). Other uses mentioned were to secure cystostomy tubes (n=2), nasal oxygen tubes (n=2) and urinary catheters (n=2). The most frequent complications reported are shown in Table 1, with the majority of surgeons being concerned about tube displacement or removal, suture breaking or loosening and infection at the tube entry site.

Nine methods of tying FTS were described (Table 2). One was discounted since it was not a self-constricting dynamic suture. Two methods were excluded because they were only described once. Six methods were investigated (Fig 2). The most popular methods were Pattern A (n=8/27) and Pattern D (n=7/27).

Part 1: Comparison of suture patterns

There was no difference between suture patterns for maximum load to failure ($p=0.51$) or energy at failure ($p=0.052$). Patterns A, B, C and D had less suture slippage than E and F ($p<0.001$, Fig 3). Patterns A and D were stiffer than pattern E. Patterns A, B, C and D were stiffer than F ($p=0.012$, Fig 4). Less extension was recorded for patterns A and B compared with pattern E and F. Pattern F had more extension than patterns A, B, C and D ($p=0.002$, Fig 5). The majority (87.5%) of FTS failed by breaking at the suture knot representing the skin attachment (n=63/72). The FTS slipped over the tube with patterns E (n=4/72) and F (n=5/72) ($p=0.03$).

Part 2: Comparison of number of repeats

There was no significant effect of repeat number on the maximum load to failure (Fig 6), energy at failure, suture slippage (Fig 7), extension or stiffness. Almost all (99%) of the FTS failed by breaking of the suture at the first knot representing the skin suture, (n=45/46); only Pattern B had one example where the suture slipped over the tube.

Discussion

We were able to determine the FTS methods currently used by surgeons responding to our questionnaire and mechanically compare the most commonly used methods. Patterns A, B, C and D had similar experimental mechanical performance. Patterns E and F did not perform as well as the other patterns due to suture slippage and therefore increased extension. In the second experiment the number of repeats had no effect on the mechanical behavior of the 2 suture patterns tested. The majority of constructs failed by the suture breaking at the first knot rather than by slipping of the tube through the FTS. This implies that the chosen suture pattern may be less important than the material properties of the suture, except where the pattern is more susceptible to slipping (patterns E and F).

The optimal stiffness of a FTS construct is unknown and may be of limited clinical relevance. Ideally, suture materials should be flexible enough to facilitate placement and knot tying, [16] but have a suitable stiffness to avoid stretching under physiological load. [17]

In a previous report, [2] the authors speculated that tube securing techniques with a high peak axial force or larger displacement to failure were more secure. Failure was defined as the first sign of suture slippage, suture breakage or tube breakage. Another study set a failure limit of 100mm distraction. [15] The term displacement, distraction and/or extension refer to the amount a material is stretched when a load is applied during mechanical testing experiments. For a FTS pattern, this variable is quite complex as it is altered by a combination of the suture material and tube material properties. There is no defined acceptable extension of a FTS construct and as such we felt that suture slippage would be a more appropriate variable to assess because slipping of a tube through an anchoring construct is undesirable. However, it is unclear how much tube displacement or slippage through a FTS might be considered practically relevant. We set a maximum suture slippage of 40mm before defining failure by suture slippage which is more stringent than previous reports since we felt it was more clinically applicable. Also, observation of the video footage showed that sutures failing to grip for 40mm all continued to slip until the entire length of the tube pulled through the FTS.

We found that as a consequence of the suture having throws on opposite sides of the tubes in patterns E and F, the suture did not lie adjacent to the tube wall and we suspect could not create adequate friction and grip the tube as it was pulled. We also found that when tying patterns E and F it was difficult to maintain tension along the entire pattern, and we speculate that this contributed to the inferior performance of patterns E and F. Whilst surgeon experience tying these constructs over several years could mitigate this problem, we should not dismiss these findings based on conjecture and instead rely on the objective mechanical performance results of this study. As such, we recommend that patterns E and F should not be used for securing indwelling tubes.

Patterns B and D were selected when comparing the effect of different numbers of repeats along the tubes on the mechanical behavior of the constructs because they had performed consistently well in the first part of the study. We found there was no difference in the mean slippage of the patterns as a result of altering the number of repeats. However, two of the constructs with 2 repeats failed by massive slippage and we suggest that patterns with a minimum number of 4 repeats should be used for greater reliability.

We chose monofilament nylon as it is commonly used to suture skin incisions and secure tubes. Investigation of absorbable multifilament materials to create FTS has been performed [15] but we did not feel that this would be useful. Multifilament materials degrade, can wick fluid and bacteria, and monofilament non-absorbable suture is the material of choice when placing extracorporeal anchoring constructs for tubes. [1, 2] Three metric material was chosen as a commonly used clinical diameter. [1, 2, 15] We used 18 French diameter custom manufactured polyurethane esophagostomy feeding tubes. Polyurethane tubing is a commonly used material for indwelling tubes and the group of surgeons that responded to our questionnaire frequently used FTS to secure feeding tubes. In a previous investigation of suture anchoring techniques [2] tube diameters of 8 French (jejunostomy), 20 French (gastrostomy) and 24 French (thoracostomy) tubing were used. That study found that the smaller 8 French diameter tubing was more prone to tube breakage than tube slippage or suture breakage. Ricker et al. [15] tested infrequently used 5 French diameter tubing and found that all the polypropylene tubes failed by deformation because the tube was too small.

Most of our suture constructs failed by breaking at the first knot, which is similar to other studies where sutures were anchored in the skin of cadavers [2] or leather pieces [15] rather than a direct attachment to the base of the materials testing machine. In those reports, none of the sutures pulled out of the skin or leather. Therefore we removed this additional variable to allow a more robust comparison between different suture patterns. When a suture material is knotted, it can be weakened by 10-40% [18] due to shear stresses that exist at the point between the loop and the first throw of the knot. [19, 20] Logically, any pattern capable of resisting significant slipping of the tube through the FTS may therefore be an acceptable choice in a clinical environment if the first knot is the weak point. However, if no negative factors result from selecting the pattern that resists the greatest load to failure in mechanical tests, nothing is lost by choosing the strongest construct to maximize resistance to tube pullout. On analysis of the video recordings, the esophagostomy tubing occasionally kinked just prior to suture failure, but this did not lead to plastic deformation and luminal occlusion.

Forces other than axial distraction may be exerted on FTS in the clinical setting, but these have not been investigated. Axial loading represents a situation where a sudden force is applied to the tube. For example, the patient pulling on the tube or the tube getting caught on something. Cyclical loading, cadaveric or live animal studies may provide further information on the mechanism of suture failure.

There is no literature defining the optimal force when tightening a FTS to achieve slight indentation of the tube. One would expect this to vary depending on tube material and diameter. We did not use a uniform force when tightening the FTS throws and knots, which may have ensured greater consistency between our constructs. However, the same board certified surgeon with several years of experience tying FTS was used to minimize variability between constructs. Further investigation would be necessary to determine differences between surgeons.

Our data cannot be extrapolated to consider different tube and sutures materials, diameters or clinical performance in vivo. Measures should always be taken to monitor indwelling tubes secured by FTS, and avoid patients from interfering with the system, such as Elizabethan collars, bandaging and tube care.

This study provides clear descriptions of how to tie several FTS patterns currently used by veterinary surgeons using clinically relevant suture and tubing materials. We are the first study to find that different FTS patterns affect the mechanical characteristics and failure mode of the constructs. We do not advocate using patterns E and F due to the risk of suture slipping. The number of repeats may not affect performance of a FTS. Overall, patterns B, C and D performed the best using this methodology. Further study using different tube and suture constructs is warranted. Surgeons should be aware that the method of tying FTS affects the mechanical behavior of the constructs and failure mode.

Acknowledgements

We are grateful to Mike Bellinger for donation of suture materials (Ethicon, Johnson & Johnson Medical Limited, Wokingham, UK) and MILA for esophagostomy tubing (MILA International, Inc., Erlanger, Kentucky). None of the authors are affiliated with these companies.

Disclosure Statement

The authors declare no conflict of interest related to this report.

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Figure Legends

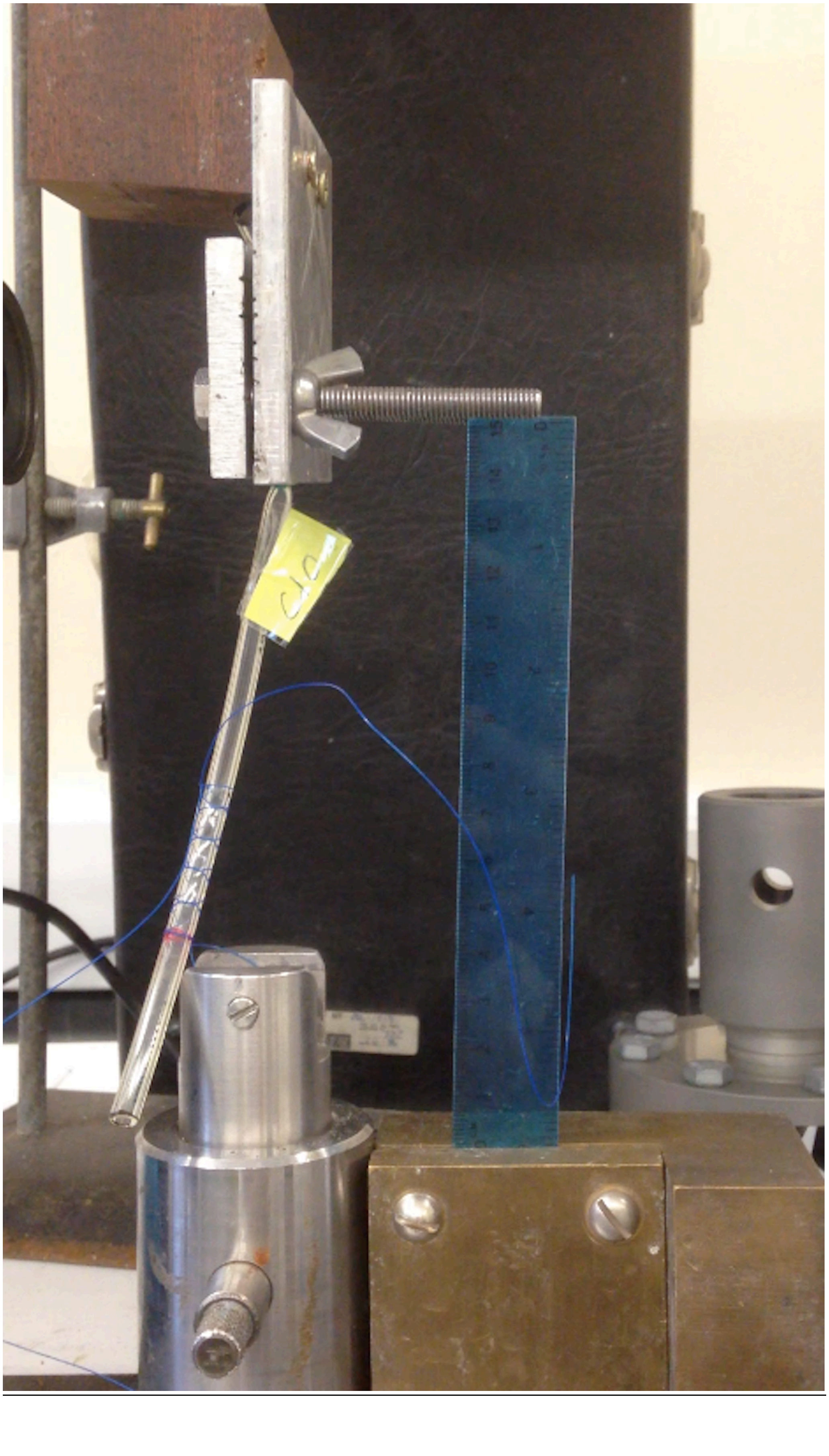

Figure 1: Experimental apparatus. The sample is held in mounted grips on the Instron machine with a ruler adjacent to the construct.

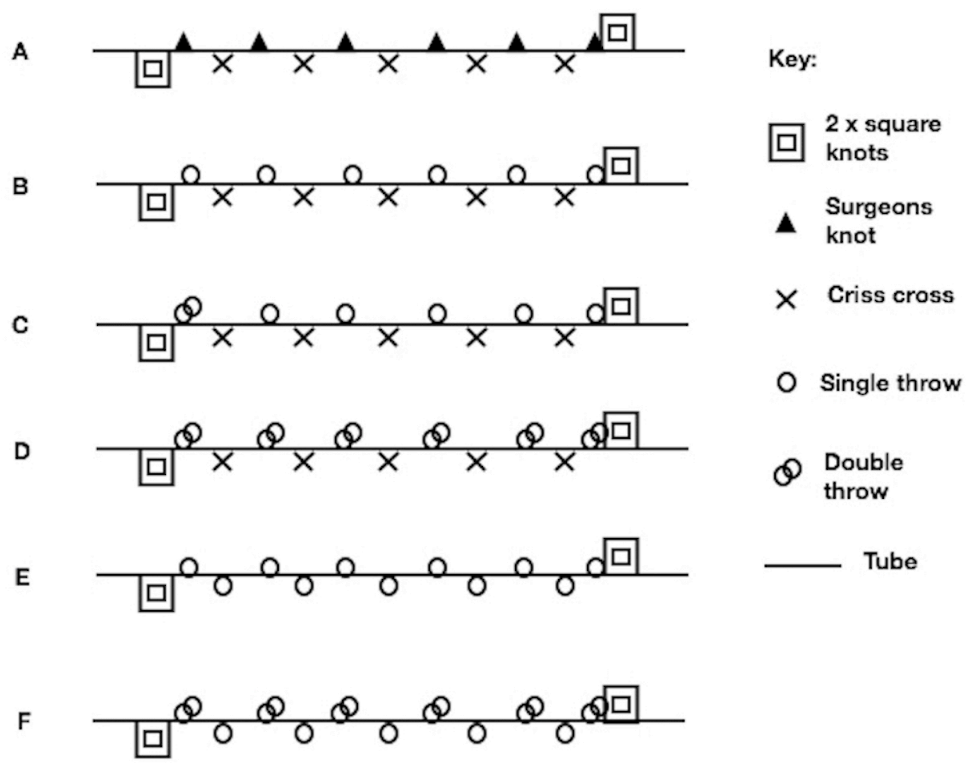

Figure 2: Finger trap suture patterns A-F each with 6 repetitions. A full description of these patterns can be found in Appendix 2.

= 2 x square knots

= Surgeons knot

= Criss cross

= Single throw

= Double throw

= Tube

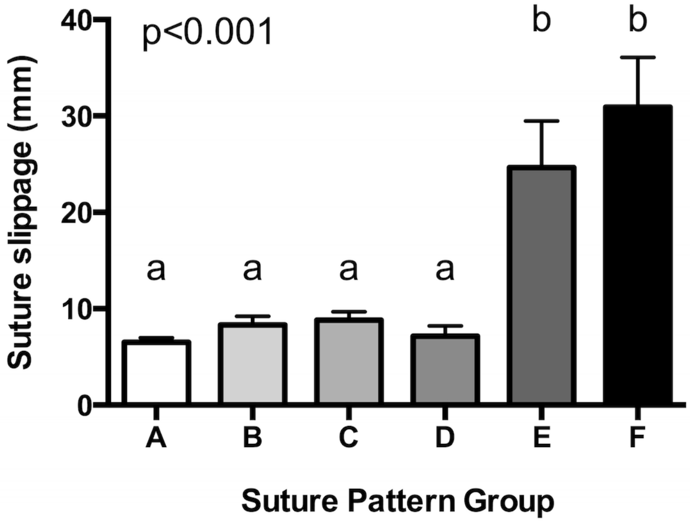

Figure 3: Suture slippage for the 6 finger trap suture patterns. Patterns with the same letter are not statistically different from one another (p>0.05).

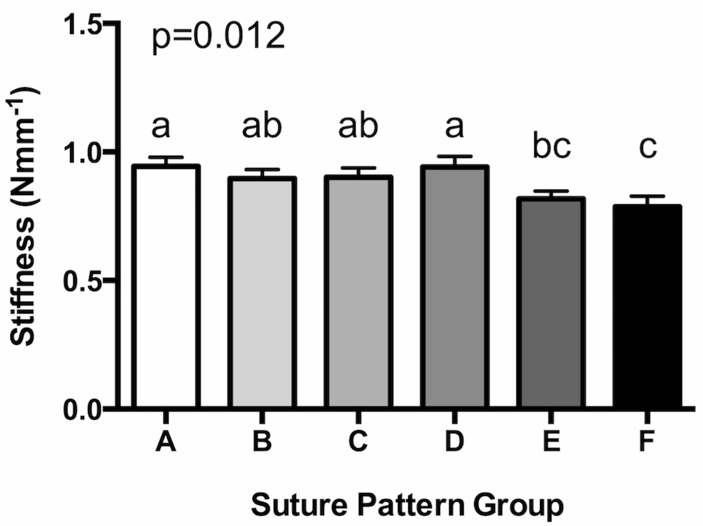

Figure 4: Stiffness for the 6 finger trap suture patterns. Patterns with the same letter are not statistically different from one another (p>0.05).

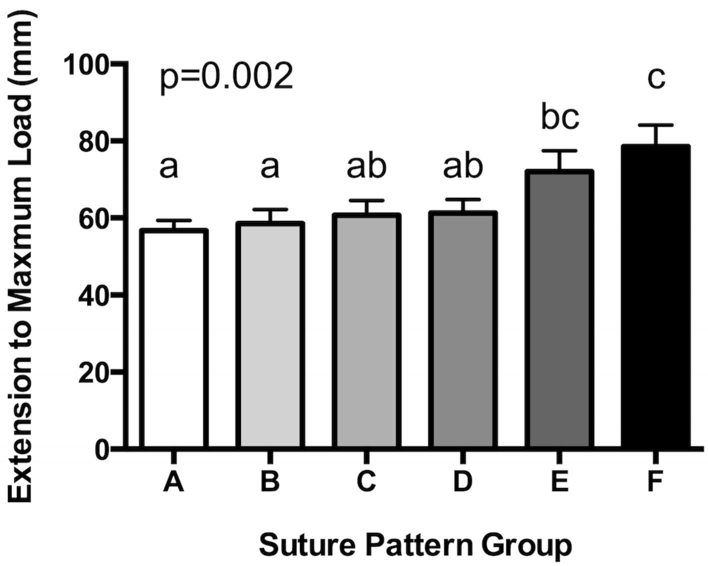

Figure 5: Extension for the 6 finger trap suture patterns. Patterns with the same letter are not statistically different from one another (p>0.05).

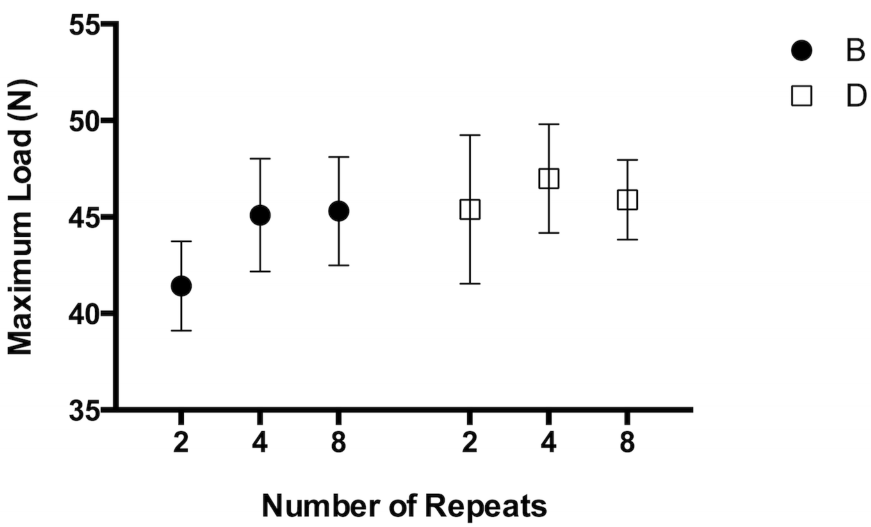

Figure 6: Maximum load to failure for the number of repeats for finger trap suture pattern B and D. No statistical difference found.

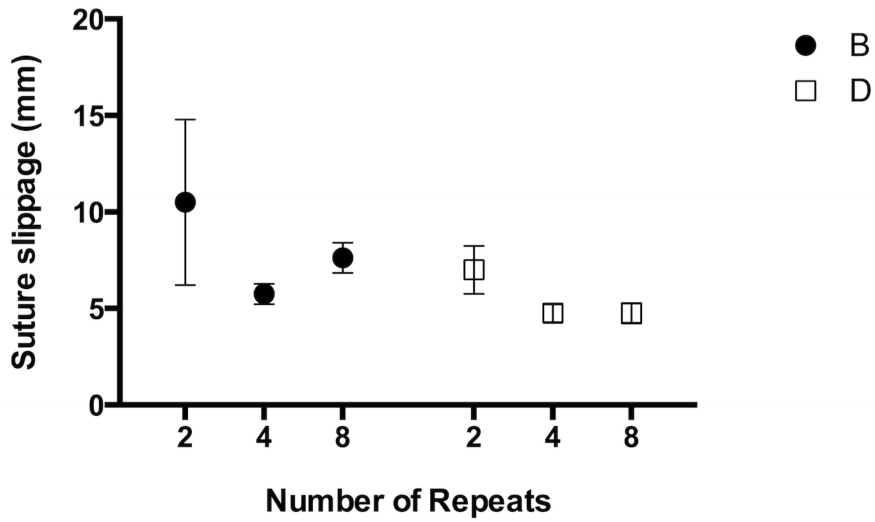

Figure 7: Suture slippage for the number of repeats for finger trap suture pattern B and D. No statistical difference found.

Table 1: Questionnaire results – complications

Complication	Number
Infection at tube entry site	13
Gradual tube displacement	10
Suture loosening	10
Suture breaking	9
Premature tube removal	7
Patient interference	6
Tube blockage	5
Pneumothorax	2
Loss of seal at drain skin entry	1
Skin irritation at skin suture	1
None	1

Table 2: Questionnaire results – methods

Number (pattern)	Method	Total number
1 (D)	Double throw and criss-cross alternated	8
2 (A)	Knot and criss-cross alternated	7
3 (B)	Single throw and criss-cross alternated	3
4 (F)	Double throw and single throws alternated	2
5 (C)	Double throw, criss-cross, then single throw with criss-cross alternated	2
6 (E)	Single throw both sides	2
7	Square knot and single throw alternated	1
8	Surgeons knot and double throw alternated	1
9	Tape placed as butterfly around drain & sutured to skin	1
Total		27